Tech Diving Mag

Research - Development - Exploration

Slab Diffusion

Even The Best Plans Go Awry...

Borongan Samar – Philippines

Cave Expedition 2015

Tec Diver = Two of Everything and Harder to Kill

Considerations of Oxygen in Diving Gas Mixtures

Issue 21 – December 2015

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Editorial

Welcome to the 21st issue of Tech Diving Mag. It's our anniversary. We started this journey together 5 years ago!

Those who reported broken links, thank you! Best Publishing Co updated their web site and now all three forms (print book, eBook and package set) of *Deep Into Deco: The Diver's Decompression Textbook* could be reached from a single page. Those who already got the book from Amazon, please put your reviews there. How does it compare to other deco-related titles? It has all the basic topics covered, and is more into decompression simulation/modeling and up-to-date research.

The contributors for this issue are world renowned industry professional Bret Gilliam, technical diving instructor trainer director Bruce Konefe and technical diving enthusiast Warren Zeman. Take a look at their brief bio at www.techdivingmag.com/contributors.html.

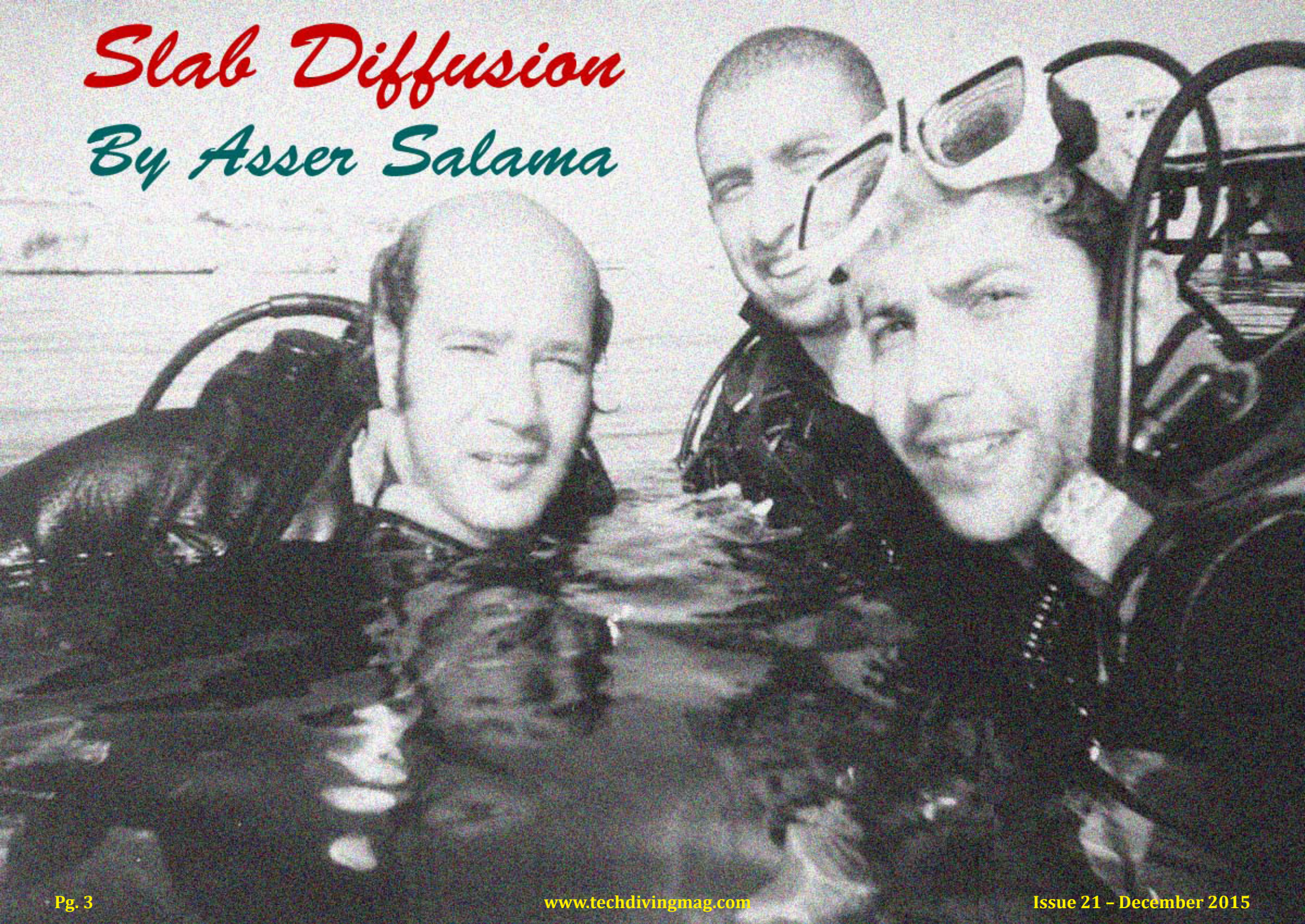
Tech Diving Mag is based on article contribution, so you're always welcome to volunteer a piece and/or some photos. The guidelines could be found at www.techdivingmag.com/guidelines.html.

This is very much your magazine, so if you want to share some views, just drop a line to asser@techdivingmag.com. And please subscribe to the newsletter at www.techdivingmag.com/communicate.html to be notified when new issues are available for download.

Asser Salama
Editor, Tech Diving Mag

Slab Diffusion

By Asser Salama



In 1952 Dr. Henry Valance Hempleman (1922-2006) introduced a new theory of decompression. His new approach was more than just a modification of Haldane's work. Hempleman noticed that the majority of DCS symptoms were manifested as limb pain, in or around the joints. He suggested that a single tissue would be responsible for that, so he based his model on one tissue only. However, a single tissue cannot fit the range of decompression if a perfusion-limited model is used. So Hempleman assumed that diffusion rather than perfusion would be how inert gas is absorbed in his single, critical tissue.[1] His assumption appears to be consistent with the poor perfusion in the cartilages around the joints.

Hempleman modeled the joint as a slab of tissue lacking blood vessels. One face of the slab is well perfused, and the inert gas is diffused from this face to the inner parts of the slab. The inert gas supply to the slab is defined by a diffusion equation rather than compartments and halftimes. After some mathematical derivations, Hempleman concluded that the quantity of inert gas entering the slab would be equal to the ambient pressure multiplied by the square root of time.

Q = Ambient Pressure * SQRT (Time)

The NDLs produced by Hempleman's model matched to a great extent those of the U.S. Navy (empirically derived). For decompression dives, the model staged the diver according to the same equation, along with an arbitrarily chosen tolerable level constant.

In 1960 Hempleman challenged another basic assumption of Haldane's, which is that gas uptake and elimination take identical times. He presented evidence from animal studies that the uptake and elimination of inert gases are not symmetrical and assumed that the elimination process is one and a half times slower than that of the uptake.[2] This is what we now refer to as asymmetric gas kinetics. The Royal Navy adopted Hempleman's work. Known as Royal Navy Physiological Laboratory (RNPL) tables, they were first published in 1968; a modified version was published in 1972. The BSAC adopted a version of the 1972 modified tables until they published their own set in 1988.

References

1. Hempelman HV. Investigation into the Decompression Tables. Report III, part A. A new theoretical basis for the calculation of decompression tables. Royal Naval Personnel Research Committee, Underwater Physiology Subcommittee Report 131. London: Medical Research Council; 1952.

2. Hempleman HV. The Unequal Rates of Uptake and Elimination of Tissue Nitrogen Gas in Diving Procedures. Royal Naval Personnel Research Committee, RNP 62/1019, UPS 195, RNPL 5/60. London: Medical Research Council; 1960.

Excerpted from *Deep Into Deco: The Diver's Decompression Textbook*. The title is available at:

https://www.bestpub.com/books/scientific-diving/product/428-deep-into-deco-the-diver-s-decompression-textbook/category_pathway-42.html

http://www.amazon.com/Deep-Into-Deco-Decompression-Textbook/dp/1930536798

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"*Deep Into Deco* is a stimulating read which covers almost every facet of diving from breathing to technical decompression. It is well referenced and dives into (forgive the pun) great detail concerning the past and present of diving theories. I recommend this book for all divers from novice to technical expert because Asser Salama makes even the most difficult topics seem easy and understandable. No diving collection is complete without this super overview book. I will keep mine on the coffee table as a discussion piece."

—Commander Joseph Dituri,
US Navy Saturation Diving Officer (ret) and Vice President of IANTD

"This book is long overdue. And it's worth the wait. What Asser Salama has accomplished with this book is remarkable. He has taken that early history of experimental trial and error and produced a stunning reference text that brings the science into sharp focus."

—Bret Gilliam, founder of TDI

"Asser's book is the best general overview of decompression modeling I have seen. The information it contains is relevant to divers of all levels, from the occasional sport diver who wants to know more about how their dive computer works to the technical diver planning extended decompression dives. It certainly is a welcome addition to my dive library!"

—Jeffrey Bozanic, PhD, author of *Mastering Rebreathers*

ASSER SALAMA, a technical diver and instructor, is founder of *Tech Diving Mag* and developer of Ultimate Planner decompression-planning software. He has a bachelor's degree in engineering and a master's degree in business administration. A software developer with an interest in decompression modeling, Salama plans to implement computational algorithms based on credible research papers to prevent some pioneering work from fading into academic obscurity.

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Even The Best Plans Go Awry…

By Bret Gilliam

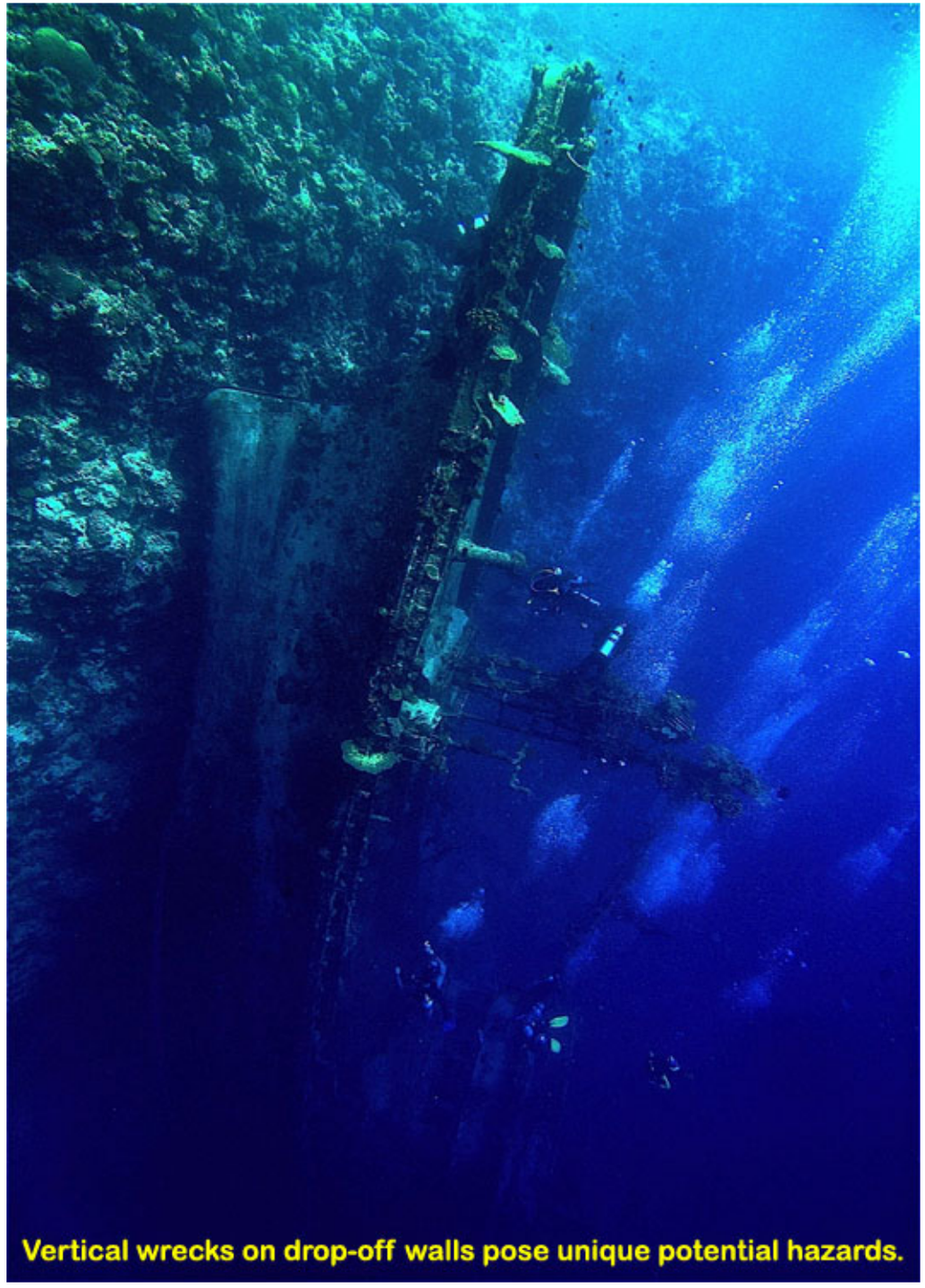
If, in a future moment of weakness, I were to ever suggest that I had seen it all in diving, please slap me and bring me back to earth. I should know by now that divers are capable of the most extraordinary behavior that can defy logic, nature, and occasionally the laws of physics. Some of them can even manage to do all of that at once. Sort of a divers' Triple Crown.

Surprisingly, many of the most memorable episodes I've had occasion to witness happened in training. In theory, instructors agree that mistakes made under supervision can be turned into positive learning experiences. Depending on the seriousness of the mistake, they can also lead to premature aging and migraines of biblical proportions for the instructor who must now leap to the rescue when the class decides to behave like Forest Gump on acid.

As ORCA computer engineer Paul Heinmiller once confided to me back in the early nineties, "Bret, we've given up on trying to make our equipment foolproof. The fools are just too ingenious."

I envision Curt Gowdy announcing, "And now we come to the compulsory portion of the program" as entry level divers drop weight belts on their buddies, do face-plants into the dive platform, or simply mount their entire scuba package upside down all the while grinning insanely like a donkey eating briars. In technical diving we see fewer incidences of the classic blunders. No, tech divers have a lot more experience so they get a bye from the preliminaries and go straight to the medal round when it comes to screw-ups.

Consider the following tale of best intentions that swiftly took a turn into the Far Side:



Vertical wrecks on drop-off walls pose unique potential hazards.

Back in 1992, I was finishing up a training dive on the wreck of the *Hydro Atlantic* off Pompano Beach, Florida with Dave Hermel, an eager tech diver from Minnesota. Dave had already made several dives on the massive wreck and we had just completed some emergency skills and were making our way back to our up line when we noticed a big grouper acting strangely. The fish made repeated headlong rushes at Dave only to stop short and literally rebound from him. Displaying the usual caution shown by the inhabitants of states where cows outnumber people, Dave kept a respectful distance and sized things up.

It turned out that his antagonist had been hooked by a passing boat and managed to break the line. But the stainless steel leader, all eight feet of it, was still attached and had snared into a deck fitting on the wreck at 145 feet. Quick as a wink, Dave gave me a "Wild Kingdom" signal loosely translated to "I'll save this beast from a lingering death and free him". I should have known better. Marlin Perkins would have.

The tale of the tape would show a pretty even match. Dave dressed out at about five foot seven and maybe the weight of an East German female javelin thrower, a svelte 160 pounds or so. The grouper gave away some weight but had the edge in power, quickness, and probably youth. And, of course, the fish was in his element and Dave was decidedly out of his. Unless the venue could have been changed to a dairy products derby with the contestants diving on a giant cheese wheel wreck in a milk vat. Not a chance, the grouper had home field advantage.

Dave went hand over hand down the wire leader until he got about two feet from Mr. Big who was eyeing him with a look like I save for any doctor who starts pulling on a rubber glove. The two worlds collided when Minnesota Man reached for his knife and Cujo, the Grouper from Hell, decided that he was about to star in a watery re-make of *The Yearling*.

In the space of 90 seconds, the star crossed pair disappeared in an explosion of silt and bubbles. Imagine what it would be like to be attached to the end of a giant air hose suddenly cut and whipping around like a Twister ride at the local carnival. A 40 pound fish can totally humiliate a much larger man and let me say, with all charity, that Dave received a bondage and discipline lesson not to be found elsewhere... outside of New Orleans' French Quarter on a late Saturday night.

When the water finally cleared I was treated to the surreal scene of diver and fish neatly bound together and firmly wired to a deck cleat. It was a rigging job worthy of a bos'n's mate. Neither party could move. The fish had even managed to ensnare both of Dave's hands in the leader and most of one leg so that he perhaps most resembled a neatly tied up boneless pork roast. A few weak squeaks bubbled out of his mouthpiece at me.

Now was the perfect time to renegotiate the course fees, but somehow I couldn't bring myself to take advantage of him in such dire straits. No, I'd shame him later back on the boat. A few minutes of diligent reverse wire sculpture freed Dave. He and the grouper parted company like Tony Curtis and Sidney Poitier in that old chain gang movie. Not exactly friends, but they had to admit they'd miss each other.

Lessons were learned all the way around. And I never again would dive without a pair of EMT scissors capable of cutting through Kryptonite.

Decompression doesn't have to be boring or tedious: following the contour of the bottom as you ascend from a drop-off wall can provide great entertainment at your stop depths. Peter Meyer enjoys a school of bigeye jacks at his 30-foot deco stop in Papua New Guinea.

Another time I had a large group of tech divers on the same wreck who completed their dives and deployed their lift bags to do drifting decompression. My charges were routinely hanging out when another dive team began to surface beneath us. Warning bells went off in everyone's minds when one diver produced a lift bag the size of the *Hindenberg* and happily began to inflate it down around forty feet.

Of course, as the bag gained buoyancy it began to do its own graphic interpretation of Boyle's Law and the hapless diver struggled to swim down against the apparition that was now starting to look like a figure from the Macy's Parade. He was almost holding his own when he fouled the line in his knife sheath around his ankle. At that point he was on a one way ride to the surface... backwards and upside down. Harnessed to the lift bag now with the approximate displacement of Marlon Brando, the diver exploded into the atmosphere with a more than passable impression of a Polaris missile. He was retrieved by the boat crew and divested of his parachute none the worse for his brush with mortality. So much for the little quirks and subtleties of using lift bags and reels.

Finally, I still love the guy who was ready to enter the water from the high mid-section of a west coast dive boat and realized he had forgotten to put on his weight belt. Under the burden of his double tanks, he backed up to a stanchion to steady himself against the boat's roll and proceeded to buckle up his belt. Around the stanchion. Stepping off he managed to almost get this fins in the water before fetching up hard when the belt reached the bottom of the rail. Suspended like some mutant crucifix against the boat's hull, he rattled around helplessly until someone cut him free. Life's lessons are taught hard sometimes.

Although these anecdotes are humorous, there is a serious undertone to my message. Don't try to shortcut the learning curve. Get into a proper training program where a qualified professional will be able to show you how to avoid problems from the outset. And at least he'll be there to get you out of a mess if your creative imagination creates a predicament that neither of you had foreseen. Your instructor may save you some embarrassment or even your life. It's all part of the experience and everyone makes mistakes. The key is surviving them.

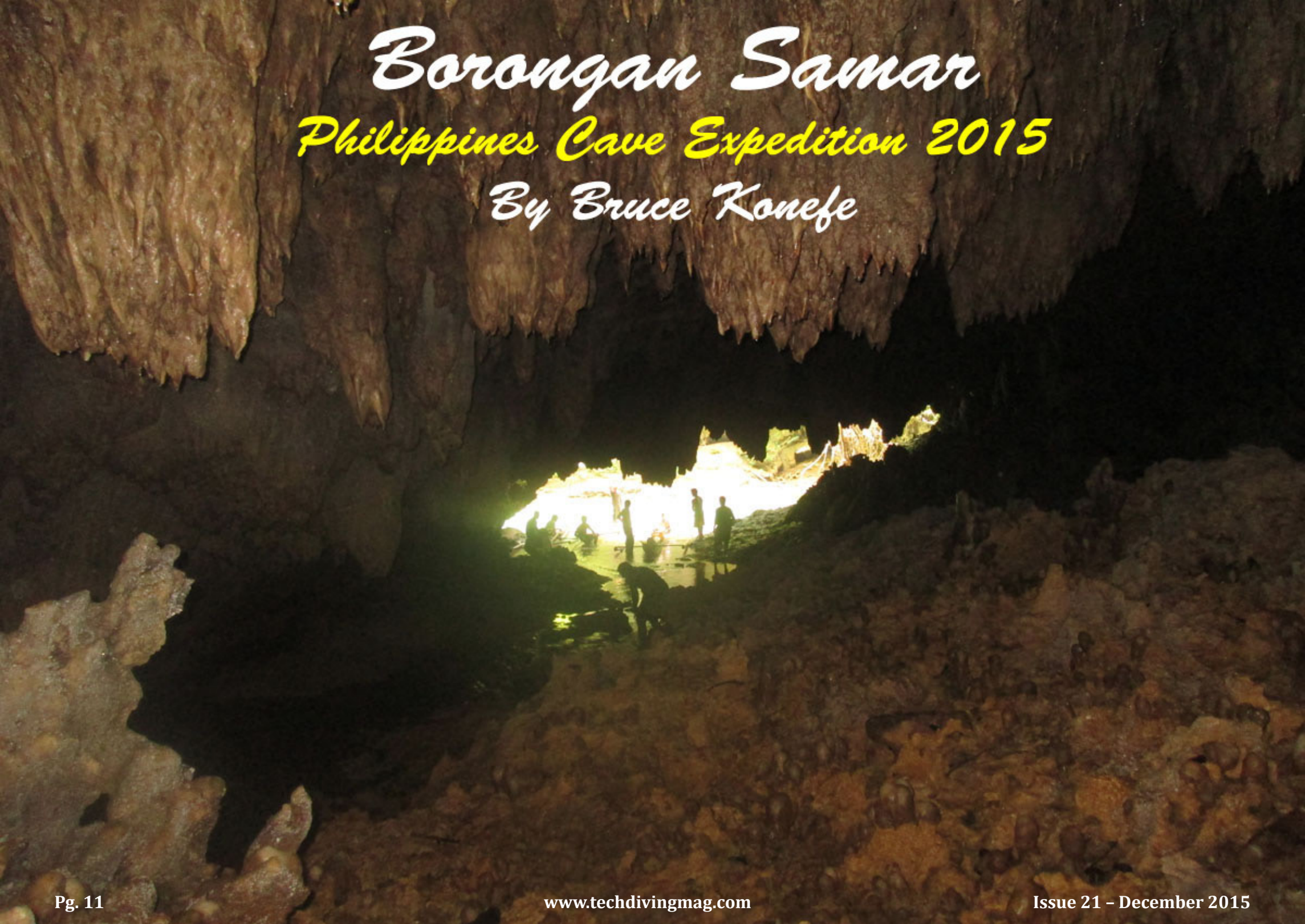
Now let's talk about the guy who tried to breathe off his argon bottle... he was unconscious, but extremely well insulated!


Special diving practices need to be thoroughly covered in waivers and briefings.

Borongan Samar

Philippines Cave Expedition 2015

By Bruce Konefe



Samar is one of the fastest growing cave diving locations in the world. Samar has produced some of the longest and deepest caves of the 7107 island of the Philippines. After a three year absence from the exploration world, Team leader Bruce Konefe hooked up with Lee Butler and Martin Ro of Savedra Dive Centre, from Moalboal, both highly qualified cave divers.

The team members met up in Tacloban Leyte and traveled 5 more hours to the eastern side of Samar to a town called Borongan. There we met up with are local Filipino guide Eleazar T. Labtic (Zar) of Huplag Speleo. Zar would take care of arranging all of the porters, accommodations and boats we would need for the trip.

The objective of this trip was to check out all four of the caves that we knew about. This trip we would just do just one dive in each cave to find out which ones had the best possibilities.

Somethings that's always in your mind when exploring new cave locations is the cave can wall-out after one meter, or can go on for miles. Every new possibility needs to be thoroughly inspected, you never know, that hole could open up into one of the largest passageways imaginable.

The evening before the actual exploration we had met up with Zar to plan what we would be doing the next day. We had to figure out how many tanks and how much equipment we would need to take. This would also determine on how many porters and boats we would need.

Day One of the actual expedition we met up at Brgy kan-Abong on the Kabarasnan river. Here we would meet the porters and transfer everything into the 3 small boats. After a 1 ½ hour ride up stream we had arrived to the first cave on the list that we wanted to explore.

We had to hike in about 150 meters to reach the sump where we would start the dive. The porters carried 6 tanks and 3 dive gear bags to the where we would enter the water. Martin was the first in the water to check out the cave and see if it was worth the time for Lee and I to kit up.

Ten minutes later a thumps up from Martin emerged from the dark water and we were right behind him. After some careful equipment checks Lee led the dive, the visibility was very good going throughout the cave but had to be careful as it was easy to silt up.

Going through the cave there was about a 2-3 m ceiling throughout. Finding a place to do line tie off was a bit hard as all the walls were waxy smooth. In order to put in some good tie offs we had to be real creative.

We headed towards what we thought was the back and then we turned around and started to check a couple of different location and

directions throughout the cave. There definitely were some very good possibilities and worth coming back to check out again.

After much discussion we decided to check out another cave that was about 30 minutes up stream. However when we were exiting the first cave we saw some very likely spots that looked dive-able. We decided to head up stream and come back for further exploration of those spots on the next trip.

The next location was also right off the river, the water was low at the entrance of the cave so we had to carry the equipment back about 50 m to get to the entrance. It was a low ceiling and one needs to take care not to bump your head.

Lee would be the one to have the first peak inside. After being down 10 minutes he surfaced and said it looked worthwhile to check out.

Martin and I kitted up and followed Lee through the cave. For all we know we were the first humans to be there, it's hard to explain the feeling you have when you are in a virgin cave, privileged and in awe doesn't carry enough weight but is a good start.

After a 1 ½ hour boat ride back we were ready for a good night's sleep, unfortunately the lack of dive centers in the area had us filling our tanks for the next day's dive on a small portable compressor. A good meal and a few cold drinks for the guys and then it was lights out.

Day Two started out just as the day before meeting up at Brgy kan-Abong. After loading up the boats we had a 45 minute ride upstream. Once out of the boats we had another 45 minute hike into the jungle. We would lead the way with the porters and equipment right behind us.

This time we were taken to an inland sink hole. Here we noticed was how cold the water actually was, it changes your anatomy a bit for sure. Martin volunteered to check out the cave, after 20 minutes underwater the cave had basically gone nowhere. The water had just drained down the mountainside and the water had settled there, the first disappointment of the trip, not bad going for an expedition, fortunately there was another cave waiting for us nearby.

We left some of the equipment where it was and had a 15 minute hike to the next one. After arriving at the fourth cave on the list Lee would have the pleasure of being the first one in.

After a quick check Lee surfaced letting us know to get kitted up. Martin had the duties of running the line and leading the dive. Unlike the other caves there were plenty of places that you could tie off all over. The floor was rock hard with very little silt. Of all of the caves

we had explored this one turned out to be the best one. Max depth was 8 meters with excellent visibility, we had laid more than one full reel of line going in and turned the dive when we hit the rule of thirds.

The day was still young so the line would be left in for a second exploration dive. On the second dive the plan was to go to the end and retrieve the line and check out some side passageways on the way out. We followed one wall and ascended into an enormous belfry-like dry chamber. The water seemed to flow through the small cracks but not large enough to have bats inside. We could spend another couple days just exploring around the inside of this cave. Hopefully next trip we can bring some additional tanks and equipment and see how far this one goes in.

Day Three was time for something different. On previous cave exploration trips we had come to some caves that we required us to do some rope and repelling work. Zar agreed to spend the time with me to help further my Single Rope Training (SRT).

There is nothing worse than hiking all day through the jungle to find out you cannot go that extra distance, going down has not been that much of a problem but coming up has. Zar had all of the proper equipment to give a briefing and demonstration on how to make the proper knots, using the lines for ascending and descending. We firmed up some future plans to extend the training in order to reach some of the caves in the Samar area.

I would like to say a special thanks to Cochran computers for help and support with the Cochran EMC20 H computers. Also thank you to Savedra Dive Center (www.savedra.com) for helping with tanks and compressors, last but not least a real big thanks to Zar Labtic of Huplag Speleo for the logistics, the trip would have been impossible without him and his team.


AQUA LUNG

Martin Ro, Bruce Konefe (team leader) and on the far right Lee Butler

Tec Diver = Two of Everything and Harder to Kill

By Warren Zeman

This was my journey from Recreational Diving to Technical Diving. I share this story with you the recreational diver who is reading about Tec diving and trying to decide if you should make the jump to the Tec side, and to all those Tec divers who want to have a laugh at the new guy. It is my hope that you can learn from the mistakes I have made along the way and that it will inspire you to make the jump to tec.

Catalina Island, Casino Point, December, the waves are big and the water was cold. I wasn't having a fun dive. The coming storm had reduced the visibility and the fading sun had plunged the whole dive site into a grayish haze. At the end of the dive those large waves made for a punishing escape up the stairs to dry land. The next day I got a call that the dive boat was not going out due to heavy seas predicted for that afternoon and the next day didn't look very promising either. That was my last dive trip before I took a break from scuba diving to focus on other expensive hobbies.

I had completed PADI Rescue a couple of years before and hadn't been interested in taking any additional classes so my diving had plateaued. In the first three years of certification I had steadily progressed each year from Open Water, Advanced and finally Rescue, after that I turned my focus to taking trips and trying to dive as much as I could. When I say as much as I could I am pushing it because I live in Southern New Mexico. The closest diving for me was about 4 hours away so every other month I was taking a trip somewhere either locally or a couple times a year to somewhere on the ocean. My local dive shop was good at getting trips going to various locations, some much more tropical than others. Due to the economy putting a strain on everyone's discretionary spending it seemed that more trips were getting canceled due to lack of interest than were actually going. So I did what I could doing trips on my own to various lakes in New Mexico, Montego Bay and Catalina Island. They were good trips but I was getting bored of doing the same types of dives usually alone but on occasion I got to dive with some really good people so after my trip to Catalina I decided to focus on some of my other interests.

Almost four years later I got a call from my sister telling me about a trip she was planning to Hawaii. She wanted to dive while she was there. She has been certified for about seven years but to my knowledge has never been diving without me so I wasn't surprised when she asked me "Do you want to go diving and make sure I remember how before my trip". I had been thinking about dusting off my fins but I had not done much other than shuffle gear around every time I had to get something stored in my office closet. Our conversation made me decide that it was time to go diving again so I drug out my gear which had been stored for longer than I wanted to admit and started to plan a refresher trip. I quickly found out that the dive shop we had both certified with had closed and the owners were pursuing other business ventures. A new shop had been formed by some of the instructors and staff from the old shop. The new shop had tanks and could provide us with air so we were in business. My sister decided that since we were both getting back into the game again she wanted to go back to Balmorhea State Park, which by West Texas standards is open water. It is an artesian spring surrounded by a concrete pool wall and deck built by the Civilian Conservation Corps back in the 30s. It is a very popular training site for open water certifications for the region. It is where both of us got our open water certifications; it is also a place I have long ago decided not to go back to. I just seem to end up back there. So the weekend is chosen and we go back, back to Balmorhea all 20' max depth of it. It is open water I think, just barely, but it is wet and a good way to ease back into the sport in controlled pool like conditions. Guess what, I'm hooked again; I remembered how much fun I have on these dive trips and what a freeing experience it is to

float weightlessly with the fish.

After I got back from Balmorhea I started to get back into diving in a big way. I have always enjoyed reading books and novels about the sea, diving, and exotic lands so as I was looking at my bookshelf I came across my copy of *Shadow Divers* by Robert Kurson which for those who haven't read it follows John Chatterton, Richie Kohler and a small group of divers who risk their lives trying to identify a sunken German U-boat off the coast of New Jersey. The first time I read the book was during a trip to Mexico for my Advanced Open Water class and my reaction was one of I can't believe these people would take such risks in their diving. At that time the story inspired me to be very cautious and methodical in my diving to not push past my limits and to do everything I could not to be a dive accident statistic. As I reread the story this time it inspired me to expand my training and extend my own limits so that I may one day visit the *U869* and the *SS Andrea Doria*. Both wrecks lie in over 200 feet of cold murky Atlantic water. So I decided that Tec diving sounded less reckless and was something I wanted to give a go. Off to the local dive shop I went where after a quick discussion with them I decided that I could go the PADI Tec route. However they don't offer any Tec training or support so I would end up traveling to another dive center to complete my training. I decided to get the prerequisites out of the way before traveling to a suitable dive shop for training. I had originally looked at Grand Cayman or Utila as they both had shops that offered the PADI Tec program that I could get started on during a nice tropical vacation.

But first I had to fulfill the prerequisites for the PADI Tec 40/45 class. I was rescue certified so I had enough skill level I hope, I had the required number of dives with the exception of the nitrox dives, but I needed to be nitrox certified and to have the Deep Diver specialty. When I got my advanced open water card at the time it allowed you to reach 130 feet so I never pursued deep diver since 130 was deep enough anyway. Since they were required I figured I would take the Nitrox and Deep Diver specialties. So out came the wallet and bang I was enrolled in Nitrox and Deep Diver.

Warren Zeman at the Blue Hole

The Nitrox class was good, I had prepared for it by reading the PADI Manual, everything I could find on several online scuba discussion boards, as well as several Nitrox blending and diving books. I could have taught that course or so it felt. The PADI Nitrox course consisted of all academic work: reading with a few quizzes, we did a few calculations and discussed things such as Tables, Maximum Operating Depth, setting computers for Nitrox, how to analyze tanks and finally a test. I found out at the end of the course that there were no nitrox tanks in the dive shop and the shop had no plans to offer nitrox either but I walked out with a certification and one step closer to Tec.

The following month I had the opportunity to start the Deep Diver course. The first dive was offered at Blue Hole in Santa Rosa NM, which is another of our "local" dive sites. Blue Hole is a sinkhole filled with 80 feet of sparkling 60 degree water. Since the water was going to be cold and I was expecting the air temps to be on the cool side I elected to dust off my dry suit. I found the seals had not dried out and it still fit so I figured we were good to go. After driving all morning to Blue Hole I geared up and started to walk to the water's edge for dive one of the class. The instructor came up to me and informed me that "Due to PADI standards unless you can produce a dry suit certification card I cannot let you dive the dry suit in class. He went on further to state that he could not let me dive with his shop's tanks as this would be a bad example to his class". At this point I had dove this particular suit 30 or more times in both fresh and saltwater including some dives in very challenging conditions but had never pursued the Dry Suit Specialty beyond the introductory dives that I did with an instructor when I bought the suit. This struck me as going over the top for looking out for a diver's safety and more than a little like the hard sell trying to get another class sold. I quickly secured some rental tanks from another dive shop and proceeded to dive for fun while they worked on their class. I came home after that weekend with a couple more dives under my belt and a new found appreciation of the advice I had received to check out any instructor and dive shop thoroughly to ensure it meets my standards and is compatible with my goals.

At this point I decided to reevaluate my plan. I knew that I still wanted to continue to get my Tec rating but after this experience I was starting to rethink my training plan through PADI so I did some Google searching and I contacted dive shops for 200+ miles and this time I am not just asking do you offer this class and when can I take it. I am asking who the instructor is and asking them what type of diving they do. When they do Tec dives is it only for class or do they do it for fun? Also what background in diving do they have? I would ask things about gear configuration or a technical equipment question trying to get to know how they do things. I went into one dive shop and asked about getting a set of doubles O2 cleaned for nitrox. Iwas quoted a price of $150 plus the gas fill. When I said that sounded a little steep they replied "Well you knew Tec diving was going to be expensive". I quickly decided that shop was looking to see how much money it could transfer from my wallet into theirs rather than to help me further my diving and so the search continued. Finally I contacted ProTech Scuba LLC, a small dive shop in southern Arizona, 270 miles from my house because when we talked, Eric the owner/instructor listened to me, he answered my questions and made me feel that I was going to learn a lot rather than just be exchanging money for a certification card.

After a couple of email and phone conversations and some money changing hands, I now had the textbooks for TDI Advanced Nitrox and Decompression Procedures in hand. I started reading through them and quickly completed the section quizzes, which I returned by email and we discussed my answers. With that part completed I packed up the truck and headed out to Arizona eager to get to the classroom portion of the classes. Since it was January, which even in the desert meant cold enough weather that we didn't want to dive during my weekend there, class consisted of an all-day lecture and discussion regarding dive planning, gas calculations and enough scenarios to make my head spin but I was making sense of this. Other than a few mistakes I ended up with some workable dive plans and an offer to complete the dives for the certification later that summer. I also was able to complete the TDI Nitrox gas blender and SDI Visual Tank Inspection courses so I did come back with a couple of certification cards to show for that weekend.


The Blue Hole

Now armed with some knowledge and my freshly assembled and filled doubles I decided I wanted to get some dives in doubles to work out any kinks and get my comfort level up before I my certification weekend. I didn't want to throw myself off a boat in Mexico only to decide I wanted to change something. I was itching to dive so when my friend called me up very excited to report that he was going to get dive certified he had two questions 1. "Where the hell is Balmorhea TX?" and 2. "Do you want to go?" I quickly offered to go with him so that he "wouldn't get lost" and if I happened to go diving I figured that would be ok too. This was how I found myself back at Balmorhea, again. It sure beat trying to learn doubles in a swimming pool. I am probably the only person to ever dive doubles with 32% nitrox in 20' of water but that was what I did. I justified it to myself as a training dive. One thing you will learn is if you dive Tec gear at recreational areas is: no one has any questions for you until you get in your gear and stand up with 80lbs on your back then they become very curious about your gear, about nitrox, and pretty much anything they can come up with to start a conversation. But we were all curious at one point ourselves so I understand. Another thing I found out that weekend was doubles are heavy but not unmanageable; they were a lot easier to dive than I first thought they would be.

Now that I was comfortable with the gear I got a weekend scheduled in Mexico with Eric to complete the certification class. San Carlos is about 400 KMs south of Nogales AZ on the Sea of Cortez and is a local favorite due to its warm water and easy drive from Arizona. After the drive down and a quick bite of lunch we were out on the dive boats. The dive boat was mostly full of recreational divers. Our plan was to do a couple of local dives to get the basic skills out of the way. I will admit that I had some issues with trim and according to Eric had the worst valve drill he had ever seen. I found that once I got to concentrating on turning valves I would start sinking and floating up a couple of feet and had a couple bounces on the bottom (it is good when you can make the instructor laugh underwater right?). After some discussion on the boat and the review of the video taken that day my next dives were better. I still need to work on my trim but I was starting to resemble a Tec diver.

The following day the plan was to get out to the island and actually get into deco, which until this point I have been really careful to avoid in my previous dives. I admit I was a little nervous about putting the theory into practice and my air consumption showed this. The island is usually great diving and this was no exception (the warm, clear water made the hour long boat ride worthwhile). After jumping in the water we kicked down to 110' and practiced more skills including gas switches, switching to my backup mask and a horizontal breath hold swim which reminded me that I need to get in better shape but I survived and we got into some light deco on this dive.

We had discussed that when he wanted me to switch masks he would tap my mask and then I would switch to my backup mask; once this was completed I figured we were done. I'm not sure I will forget the surprise mask switch during a gas switch to add "task loading". As I am switching to my deco gas here comes Eric with a tap-tap on my mask then he took my mask off. Solve one problem then continue on to the next was the lesson. I finished the gas switch and then put on my other mask once I had the regulator in place; being able to see is less important than not having something to breathe. At least I got to go back to my primary mask which did not leak.

Our next dive was to be the "big one" 150' for 15 minutes. We were attempting this dive from a location on the south end of the island which is usually subject to some current and that day was no exception. Since we were diving from a boat filled with recreational

divers and some open water students the boat was anchored in the shallows and our plan was to go down the anchor line and swim for the deep blue. Once we swam away from the little cove where the boat was anchored we found ourselves fighting the current just to get far enough out to make 140' where we hit our 15 minute time and had to turn the dive. I was a little surprised that as we ascended we hit a second current running counter to the current we had been swimming into during the deep portion of our dive. I had experienced this once or twice but never at this end of the island and now after this wild ride we both were less than sure of where we were. I shot the bag and got ready to do a drifting deco and possibly a long swim back to the boat. I kept thinking to myself you may be lost but you must complete the planned deco and surface safely before anything else. So while I kept an eye on the time, depth, the deco schedule, and ran the reel Eric kept an eye compass as we swam back toward the island hoping that once we got closer to the island we would get out of the current. Suddenly as we reached the 40' stop the current disappeared and we spotted our boat's anchor line. We were able to complete the rest of our deco next to the boat watching the sea lions play among the divers who had invaded their island home. Once we cleared deco and surfaced I asked if Eric was as surprised as I was to find the boat he said he would have been happy just to find the island after a dive in that current.

Our final day was a couple of local dives again which were skill building dives to catch up on any skills I needed to work on and continuing the work on my trim and propulsion. I was able to do the valve drill without bouncing off the bottom like Wile E Coyote, I still drifted around but it is getting better. I did make Eric laugh when I attempted to do the backwards kick which normally ends up pitching me head down and this time due to the slight current we were in I ended up doing a complete somersault. All in all I would consider that weekend to be a good start in my Tec diving journey. Some of the things I took away from the class were that Tec diving was more about being able to plan and problem solve more than any other tasks. Most of the new skills weren't any harder than the ones you had to complete in your basic certification class there were some new skills that were all geared toward solving problems underwater, such as shutting down a free flowing regulator to prevent the loss of all of your breathing gas and helping your teammates out, trading gas bottles during deco etc. Things do get more complicated when you can't just shoot for the surface when something goes wrong. I come out of the class better prepared for the things you will face on big dives. You end up going diving with two of almost everything but that gives you the tools you need to become harder to kill.

Considerations of Oxygen in Diving Gas Mixtures

By Bret Gilliam

Oxygen is the most basic life support system our bodies employ, and yet also has the capacity to cause great harm. Keller (1946) has called oxygen "The Princess of Gases. She is beautiful but has to be handled with special care". We cannot live without it, but in prolonged breathing exposures or in deep depths on standard air scuba systems too much of a good thing can prove fatal.

Thom and Clark (1990) note, "paradoxically, the same gas that is required to sustain life by preventing loss of consciousness and death from hypoxemia has toxic properties that affect all living cells at sufficiently high pressure and duration of exposure." Most divers are familiar with the basic characteristics of oxygen as it occurs in our atmosphere. It is a colorless, odorless and tasteless gas found free in dry air at 23.15% by weight and 20.98% by volume. For discussion purposes, we will consider its volume percentage to be 21%. Interestingly, the relative toxic effects of oxygen are determined not by the percentage in any mixed gas (including standard air at approximately 21% oxygen and 79% nitrogen), but by the oxygen partial pressure (PO2).

A review of Dalton's Law of Partial Pressures is helpful (The total pressure exerted by a gas mixture is equal to the sum of the partial pressures of the components of the mixture i.e. P = P1+P2+P3...etc.), but put simply, as depth increases a corresponding elevation in the partial pressure of oxygen is achieved and must be considered by any diver planning deeper exposures. At the surface we are naturally adapted to PO2 at .21 atmospheres absolute (ATA). This is considered the reference point for "normoxic" conditions.

It is important to be aware of certain ranges of tolerance in normal, healthy persons. Most people can maintain proper blood oxygenation down to .16 ATA (16% oxygen in the mix at surface pressure) but dropping much below this will limit performance/endurance and unconsciousness will likely result approaching .1 ATA (10% oxygen at the surface).

As a physics reminder please note that we commonly refer to the percentage of a gas in any mixture as the Fg (fraction of the gas expressed as the decimal equivalent); thusly the FO2 at the surface can be correctly expressed as .21; Pg or partial pressure of a gas may be expressed as the Fg multiplied by atmospheres absolute or ATA's. Therefore, the PO2 at 66 fsw is properly expressed as .63 ATA of O2. This is derived from multiplying .21 (the FO2 of oxygen in AIR) by the pressure in ATA's: .21 X 3 = .63 ATA's of O2. Though the FO2 will remain constant, the PO2 will increase with depth.

The diver may recall the old reference to the "Ten and Ten Rule" wherein it supposed that blackout will occur if the percentage of either oxygen or carbon dioxide ($C0_2$) reaches 10% in the gas mixture. This was particularly important to competitive free divers and spearfisherman while holding their breath and attaining depths in excess of 80 to 100 fsw (24.2 to 30.3 m). Many of these individuals could reach far deeper depths through applied disciplines of hyperventilation and adaptation in conjunction with techniques employed to precipitate the "diving reflex" to extend time underwater. This practice, however, is a double edged sword: as depth increased carbon dioxide was produced by the body's metabolism, and absent any other source of oxygen, this "O_2 storage" advantage was depleted. To a certain degree this was counterbalanced by a corresponding rise in the percentage of CO_2 in the system since this gas is a metabolic waste product as O_2 is burned.

The relationship is important because high CO_2 is a major stimulus to breathe while low O_2 is not. As the diver held his breath, O_2 was consumed and CO_2 eventually said, "Hey buddy, I'll continue to

hurt you unless you get back to the surface and get a fresh breath, you idiot!" Now the insidious danger occurs. As the diver ascended, both partial pressures dropped accordingly. His stimulus to breathe was reduced as PCO2 dropped while his PO2 could be dropping to dangerous levels.

At some point, the diver passed out from this "latent hypoxia" syndrome or what became commonly known as "shallow water black out". Typically the diver showed no signs or distress and simply went limp, sometimes within ten feet of the surface. Those who were successfully rescued and revived related no warning of the impending blackout or any major stimulus to breathe. But several fatalities were sustained before the problems were identified and the hazards of deep breath-hold diving were well communicated.

CENTRAL NERVOUS SYSTEM O_2 TOXICITY (Paul Bert Effect)

For the free swimming scuba diver, the most immediate dangers with O_2 toxicity are encountered in deeper depths where the PO2exceeds 1.6 ATA (218 fsw); in military, commercial and some scientific applications the ideal method of controlling the toxic effects of O_2 are to keep the oxygen dose as near "normoxic" as possible. This is accomplished by controlling the gas mixtures. A typical mix would reduce the oxygen percentage in a deep dive usage and let the elevated pressure raise the PO2 to normoxic levels. For example,if a diver needed a mix for the 300 fsw (91 m) level the O_2 could be used at only 2% with another inert gas. The affect of 10 ATA's at 300 fsw would produce a PO2 of .21 ATA, the same as we normally breathe at the surface. The dive supervisor could select a single inert gas such as helium (He) or combine two inert gases such as nitrogen and helium while keeping the O_2 percentage constant. The resulting gas mixes are commonly referred to as HELIOX or TRIMIX respectively. Realistically however, this mix would incur a greater decompression obligation due to the elevated inert gas percentages if oxygen was kept at an FO2 of .20; a .10 to .15 FO2 would be more practical.

Since traditional activities are for divers using standard air as the breathing gas, we shall consider that we do not have the luxury of custom mixing our oxygen percentages. Our gas is going to be 21% O_2 and 79% nitrogen and we are stuck with it unless the diver makes the commitment to mixed gas equipment and its attendant responsibilities. As AIR divers we will be most concerned with the acute phase of oxygen toxicity (sometimes also referred to as oxygen poisoning). Acute O_2 toxicity for well experienced and "depth adapted" divers will ultimately be the deciding factor in penetration limits, not inert gas narcosis.

The central nervous system is primarily affected in the acute phase and the following table will illustrate typical manifestations.

SIGNS AND SYMPTOMS OF CNS O_2 TOXICITY IN NORMAL MEN

- Facial pallor
- Sweating
- Bradycardia
- Palpitations
- Depression
- Apprehension
- Visual symptoms: dazzle, constriction of visual field
- Tinnitus and auditory hallucinations
- Vertigo
- Respiratory changes
- Nausea
- Spasmodic vomiting

- Fibrillation of lips
- Twitching of: lips, cheeks, nose, eyelids
- Syncope
- Convulsions

CNS O_2 TOXICITY SYMPTOMS (VENTID)
Vision: any disturbance including "tunnel vision" etc.
Ears: any changes in normal hearing function
Nausea: severity may vary and be intermittent
Twitching: classically manifest in facial muscles
Irritability: personality shifts, anxiety, confusion etc.
Dizziness: vertigo, disorientation

Even a cursory examination of these effects should illustrate the seriousness of a CNS O_2 hit in deep water. Onset and severity of symptoms do not follow any particular pattern and may vary in an individual diver from day to day. Of particular note is that there may be no warning with less serious symptoms before full convulsion is precipitated. Thom and Clark (1990) observe that "minor symptoms did not always precede the onset of convulsions, and even when a preconvulsive aura did occur, it was often followed so quickly by seizures that it had little practical value".

Many divers have relied on the incorrect supposition that lip twitching or "eye ticks" would provide adequate notice of impending disaster but this has been disproved by chamber tests and direct observation in actual dive scenarios. It is strongly suspected that CNS O_2 toxicity and/or severe narcosis played the major role in the loss of almost a dozen divers in the last two decades while attempting record dives on standard air.


Bret Gilliam running a decompression chamber, 1989.

Oxygen convulsions, per se, are not inherently harmful but imagine the implications for an untended diver or even one with a buddy near by. Management of a patent airway and rescue in such an extreme situation is near impossible and the diver will almost certainly drown.

Mount (1991) related a near miss accident he was inadvertently involved in during a deep dive in 1971. He was diving at the 330 fsw (100 m) level and in control of narcosis with no O_2 toxicity problems when he observed an obviously out of control female diver blissfully pass him with a vigorous kick cycle heading straight down! He gave chase and intercepted her near the 400 fsw (121.2 m) level. Making contact and arresting her plunge required heavy exertion and power kicking strokes to initiate ascent for the pair. "Within seconds after this effort, I had almost complete visual collapse. I found myself looking through a solid red field with black spots; basically blind. I made it up to the 300 fsw (90.9 m) level with her and was relieved in the rescue by other divers. By 275 fsw (83.3 m) I was getting occasional 'windows' but my vision did not return to normal until past 250 fsw (75.8 m)."

I also witnessed another case while diving on a scientific project in the Virgin Islands in 1972. My regular buddy and I were gathering samples at 290 fsw (87.9 m) as part of an on-going survey. We were both well adapted from daily deep diving and routinely worked this depth without difficulty. On this occasion, another scientist diver had joined us at his request. In prior discussions, he had satisfied us that he was familiar and experienced with deep diving procedures. About seven minutes into the dive we watched him begin hammering away on a coral sample for retrieval and suddenly go limp. I caught him as he started to fall over the drop-off wall and ventilated him with his regulator's purge valve while rapidly ascending. At 190 fsw (57.6 m) he completely recovered and began breathing on his own. He was unable to recall anything except beginning work with his hammer. This incident finally stopped the university's practice of forcing outsiders on our professional teams. It was sheer luck that I happened to be looking his way when he passed out.

Most cases of underwater blackout result in death. The dangers of this type of CNS O2 toxicity cannot be too greatly emphasized. On AIR, at 300 fsw (91 m) or 10 ATA, the PO2 has reached 2.1 ATA; this partial pressure will **definitely** produce toxicity limited only by time and other influences such as elevated PCO2.

For these indisputable facts, the practice of AIR diving deeper than 300 fsw (91 m) must be placed in the perspective of assumable risk of **sudden death** not just injury.

It should be noted that divers routinely push nearly 3 ATA pf O2 in recompression chambers for extended periods. Theoretically, chamber divers are supposed to be at rest but many of the bounce dive profiles practiced by extreme deep AIR divers include performance plans that essentially have the diver "at rest" in the water with negative descents and controlled buoyant ascents in the toxicity range.

Neither Watson and Gruener (1968) or the author (1990) suffered O2 toxicity problems on their record dives to 437 and 452 fsw (132.4 and137 m) respectively but their times in the critical toxicity zone were limited and they each had practiced exceptional adaptive techniques. (In spite of this, Watson and Gruener reported near total incapacitation due to narcosis.)

When I was involved in very deep diving on projects in the late 1980s that ended up leading to setting a new record for depth in February 1990 at 452 feet, I believed that adaptation was proven to narcosis as

well as to onset of O2 toxicity and was able to effectively limit narcosis impairment. But my primary concern from the very beginning was O2 toxicity. My tables were based on fast descents and fast ascents in the "Tox zone." I felt I could tolerate up to five minutes below 300 feet and still get out before the high PO2 would hit me. In retrospect, of course, it worked.

Other factors in my success include almost absurdly low respiration and heartbeat rates, repeated progressive deep exposures and limited physical exertion. Like narcosis, O2 toxicity can be precipitated by higher CO2 levels generated in work tasks or simply swimming harder. Deep divers need to develop strong disciplines for energy conservation and focused breathing habits. The double whammy of sudden onset and increased severity of narcosis and CNS O2 toxicity in a stress situation can rapidly accelerate a borderline control situation into a disaster. The U.S. Navy still conducts oxygen tolerance tests in dry chambers to screen individuals with unusual susceptibility to O2. However, highly motivated individuals may escape detection anyway. Both Mount and Rutkowski have served as chamber supervisors and conducted such tests. In 1991 when interviewed, neither could recall any instances where a pre-screening O2 tolerance test was failed. The validity of such test protocols remains debated.

The following table gives the oxygen partial pressure limits during working dives as recommended by NOAA. This will provide some parameters for dive planning and is deliberately conservative. The scuba diver should be safe within these limits presuming good physical fitness and no predisposition to toxicity such as heavy smoking habits or asthma conditions. No guarantee of safety can ever be presumed.

NOAA PO2 And Exposure Time Limits for Working Divers

Normal Exposure Limits

Feet of Seawater fsw	Oxygen Partial Pressure (PO2) in ATA	Max. Duration For Single Exposure in min.	Max.Total Duration / day in min.
218	1.6	45	150
203	1.5	120	180
187	1.4	150	180
171	1.3	180	210
156	1.2	210	240
140	1.1	240	270
124	1.0	300	300
108	.9	360	360
93	.8	450	450
77	.7	570	570
61	.6	720	720

Exceptional Exposures

281	2.0	30
266	1.9	45
250	1.8	60
234	1.7	75
218	1.6	120
203	1.5	150
187	1.4	180
171	1.3	240

Given the now mainstream usage of nitrox mixtures and other mixed gases that may provide oxygen in the mixture at a greater or lessened percentage than that of air at an FO2 of .21, the following table has been provided as a handy reference for maximum depths on various FO2 to remain within recommended limits of exposure.

MAXIMUM DEPTHS FOR A GIVEN FO2 GIVEN A LIMITING PO2

FO2	1.4 ATA fsw	1.6 ATA fsw
0.15	275.00	319.00
0.16	255.75	297.00
0.17	238.76	277.59
0.18	223.67	260.33
0.19	210.16	244.89
0.20	198.00	231.00
0.21 (normoxic)	187.00	218.43
0.22	177.00	207.00
0.23	167.87	196.57
0.24	159.50	187.00
0.25	151.80	178.20
0.26	144.69	170.08
0.27	138.11	162.56
0.28	132.00	155.57
0.29	126.31	149.07
0.30	121.00	143.00
0.31	116.03	137.32
0.32	111.37	132.00
0.33	107.00	127.00
0.34	102.88	122.29
0.35	99.00	117.86
0.36	95.33	113.67
0.37	91.86	109.70
0.38	88.58	105.05
0.39	85.46	102.38
0.40	82.50	99.00
0.41	79.68	95.78
0.42	77.00	92.71
0.43	74.44	89.79
0.44	72.00	87.00
0.45	69.67	84.33
0.46	67.43	81.78
0.47	65.30	79.34
0.48	63.25	77.00
0.49	61.29	74.76
0.50	59.40	72.60

As in the case of Table 5-3 these depths are recommendations based on normal working conditions for the diver. In the case of gases mixed for purposes of decompression, it may possible for some divers to use deeper depths on higher FO2 values. Consult experts before attempting such higher exposures.

CHRONIC OXYGEN TOXICITY (Lorraine Smith Effect)

This effect was commonly referred to in the past as pulmonary toxicity. Rutkowski makes frequent reference in his lectures to the diver's "pulmonary clock." In the early 1990s, the term "whole body" toxicity also came into use.

This phase of O2 toxicity is less a problem for divers except in prolonged in-water oxygen decompression or in actual recompression therapy. This "chronic" toxicity is generally associated with longer, low pressure exposures as compared to the high PO2 values encountered

at depth. Due to the limits of extended hyperbaric oxygen breathing, a method of calculating the individual total O2 exposure incurred during all phases of a dive was developed. This can also be used to factor decompression and O2 treatment breathing periods. This measure is known as the Unit Pulmonary Toxicity Dose (UPTD) and tables are available for calculating UPTD's for AIR, pure O2 and mixed gases.

Hamilton (1989) notes in his REPEX paper, "The Pennsylvania unit (UPTD) has served well and is based on empirical data; it is the basic unit used in the Repex method. For two reasons, however, we prefer to use an alternative term: OTU or Oxygen Tolerance Dose. First, since we are dealing with operational physiology in managing exposure to oxygen in diving we prefer to refer to these as techniques for 'tolerance' of O2 exposure, rather than for avoiding O2 'toxicity'. They are the same thing, but we feel it offers a more positive approach."

The OTU and its predecessors are calculated by the following expression:

$$OTU = t\,[(PO2 - 0.5) / 0.5]^{0.83}$$

where t is the duration of the exposure in minutes and PO2 is the oxygen partial pressure in ATA. The 0.5 ATA is the "threshold" below which no significant symptoms develop; even oxygen injured lungs can recover below this level. (Bardin and Lambertsen 1970 and Eckenhoff et al. 1987) The exponent 0.83 was determined to give the best fit to the data on reduction of vital capacity as a function of oxygen exposure. An important benefit of this method is that the units are additive, and the net result of multiple short exposures can be totalled.

These dose tolerances were calculated originally for divers in multi-day saturation missions; scuba divers are urged to consult with experts in O2 management before attempting any dives where significant OTU doses will be accumulated. Because of the nature of the REPEX operation its algorithm does not devote much attention to acute CNS toxicity specifically. It is intended that divers just stay out of the CNS toxicity zone by staying below 1.5 ATA PO2. As a general rule of thumb, the daily OTU dose should always be calculated to allow the diver to sustain a full treatment Table 6 (approximately 650 OTU/UPTD) if necessary. Refer to the NOAA Table for suggested exposures at specific depths/ATA PO2 for scuba divers. By referencing between these two tables, the accumulated OTU dose can be accurately tracked.

For isolated or single day exposures, an 850 OTU dose can be tolerated. Second day exposures drop to a recommended 700 OTU dose level and continue to fall off over multi-day exposures. The reader is referred to Hamilton's original REPEX work for additional information.

Chart of OTU dose by PO2 and air depths. The values in the Table from left are the PO2, depth in fsw or msw diving with air to give that PO2,and the number of OTU per minute at the indicated PO2 level. To calculate a dose, multiply the value in the chart for the exposure PO2 by the number of minutes of the exposure. For exposures at different PO2's, calculate the dose in OTU for each exposure at a given PO2 and sum the OTU's to get the total exposure.

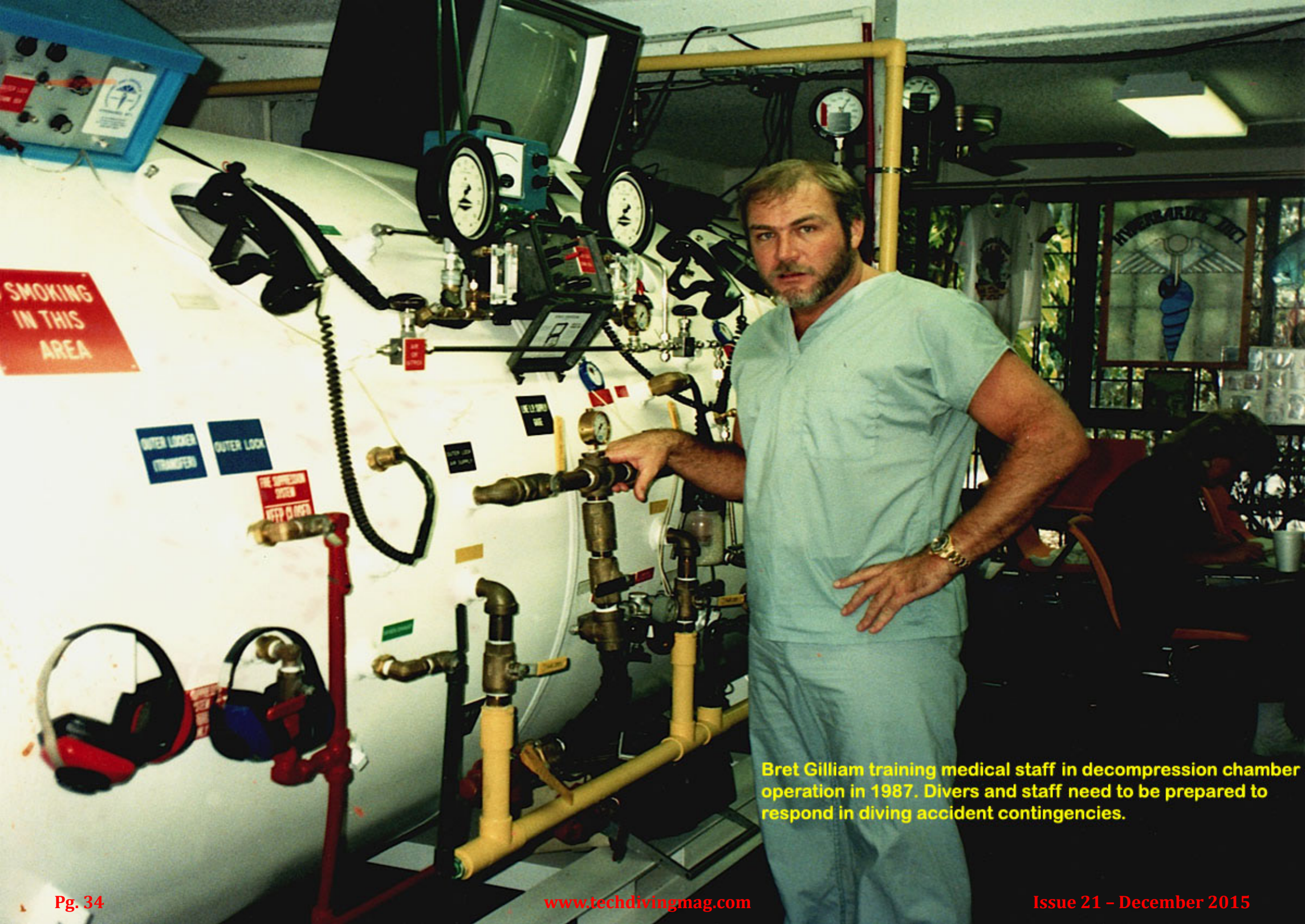
PO2 atm or bar	DEPTH fsw	DEPTH msw	OTU / min
0.50	45.6	13.8	0.00
0.55	53.4	16.2	0.15
0.60	61.3	18.6	0.27

0.65	69.1	21.0	0.37
0.70	77.0	23.3	0.47
0.75	84.9	25.7	0.56
0.80	92.7	28.1	0.65
0.85	100.6	30.5	0.74
0.90	108.4	32.9	0.83
0.95	116.3	35.2	0.92
1.00	124.4	37.6	1.00
1.05	132.0	40.0	1.08
1.10	139.9	42.4	1.16
1.15	147.7	44.8	1.24
1.20	155.6	47.1	1.32
1.25	163.4	49.5	1.40
1.30	171.3	51.9	1.48
1.35	179.1	54.3	1.55
1.40	187.0	56.7	1.63
1.45	194.9	59.1	1.70
1.50	202.7	61.4	1.78
1.55	210.6	63.8	1.85
1.60	218.4	66.2	1.92
1.65	226.3	68.6	2.00
1.70	234.1	71.0	2.07
1.75	242.0	73.3	2.14
1.80	249.9	75.7	2.21
1.85	257.7	78.1	2.28
1.90	265.6	80.5	2.35
1.95	273.4	82.8	2.42
2.00	281.3	85.2	2.49

Symptoms of chronic pulmonary O2 toxicity include shortness of breath, fatigue, dry coughing, lung irritation and a burning sensation in the breathing cycle. Pulmonary edema is most common and a marked reduction in vital capacity.

In treatments in recompression chambers, patient tenders also look for irritability in the patient or unreasonable disposition as early warning signs that dictate an AIR break in the schedule to allow some relief period. Bennet (1991) expressed concern over sport divers' use of in-water O2 decompression as possibly becoming a post-dive factor if treatment should be required later. This relates to the so-called "oxygen box" where a patient reaches the UPTD limit and can no longer tolerate O2 therapy and leaves the chamber supervisor in a quandry for a viable exit protocol. This reflected an incomplete practical knowledge of exposures and his opinion was largely rebutted by field professionals.

From a practical standpoint, pulmonary or "whole body" effects are virtually impossible to sufficiently accumulate using open circuit equipment so that they become a factor in diving planning. Some instructors with an incomplete understanding of tracking the OTU dose have mistakenly concluded that precise measurement of such units is necessary. Hamilton emphasizes that this REPEX tracking theory was designed for divers in saturation with no opportunity to return to the surface and normal oxygen pressures during the multi-day period. Thus the importance of multi-day dose accumulations became crucial to planning. However, open circuit divers eventually will have to return to the surface, if only to sleep and eat. That period is adequate to allow sufficient "blow off" time to re-set the pulmonary clock to, essentially, *zero* each day. In almost any foreseeable dive plan, the CNS limits will *always* be the controlling oxygen clock. You can prove this yourself by simply adding the OTUs for any given dive and you'll find that just to obtain 300 OTUs or more would require a superhuman dive profile that violates the exposure recommendations for the CNS clock so grossly as to make the pulmonary considerations moot.



Bret Gilliam training medical staff in decompression chamber operation in 1987. Divers and staff need to be prepared to respond in diving accident contingencies.

However, it must be emphasized that accurate tracking of the CNS clock is crucial. This includes both the bottom depth exposure *and* the decompression phase. Several accidents have occurred because divers planned only for the "depth" phase of the dive and forgot the consequences of breathing oxygen or high O2 percentage nitrox during decompression.

Here's an example:
A dive to 220 fsw on air for 30 minutes is allowable while staying inside the 45 minute single dive exposure for oxygen at 1.6 ATA. However, 88 minutes of decompression will be required (using U.S. Navy tables). Assuming the deeper stops were taken on air, it would be a common mistake for some divers to think they could safely switch to pure oxygen for the 20 foot stop. The table calls for 23 minutes at this depth. But wait: oxygen at 20 fsw brings the diver right back to 1.6 ATA again and this would place him 8 minutes over the maximum recommended limit. Convulsive events have been precipitated for precisely these types of failures to calculate the *total dosage*. What's the solution? Drop the decompression phase PO2 by utilizing an 80/20 nitrox mix which will keep the exposure at or below 1.4 ATA.

So what's happening with the pulmonary "whole body" clock? Not much. The bottom phase of the dive on air loaded about 60 OTUs and even if the entire decompression phase was taken on varying mixtures to yield a uniform 1.4 ATA O2 exposure, only about 140 OTUs would be added there. This totals right about 200 OTUs for what is a decidedly aggressive dive by any criteria. Remembering that you can take up to 850 OTUs per day (and still provide an allowance of 650 OTUs should you need to reserve them for a DCS treatment). 200 OTUs doesn't really amount to anything. In fact, you could do this same profile four more times before you ran out of exposure time on the pulmonary clock. However, the reality is that you would blow the CNS limits off the gauge and probably bend yourself as well.

So if you've been staying up nights worrying about calculating OTUs, relax. They'll take care of themselves just fine if you stay within the CNS guidelines.

SUMMARY

Both manifestations of oxygen toxicity can play a role in the deep diver's plan. Of most concern is the extremely dangerous and unpredictable CNS O2 Tox hit at depth. Divers should exercise extreme caution when venturing beyond the 1.6 ATA range and penetrations beyond 275 fsw (83.3 m) on AIR are ill-advised except in the most experienced and adapted diver.

Unlike narcosis impairment, where a quantifiable possibility of rescue exists from an alert buddy or self-recognition of problem levels can be relieved by ascent, an O2 hit can quickly progress to uncontrollable convulsive states and drowning. As divers become more attuned to management of inert gas narcosis, the O2 toxicity barrier will be the ultimate depth limit.

I cannot emphasize enough that a thorough understanding of the technical physiology issues and a comfort level in calculating the exposure is vital to any diving activity. Most current diving training programs make no effort to go into detail on this subject or to explain it adequately. Seek out a proper curriculum such as that through Technical Diving International (TDI) or simply avoid the thresholds of deeper depths entirely.

Caution is the guiding rule. Avoid Darwin's Rule at all costs…

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